

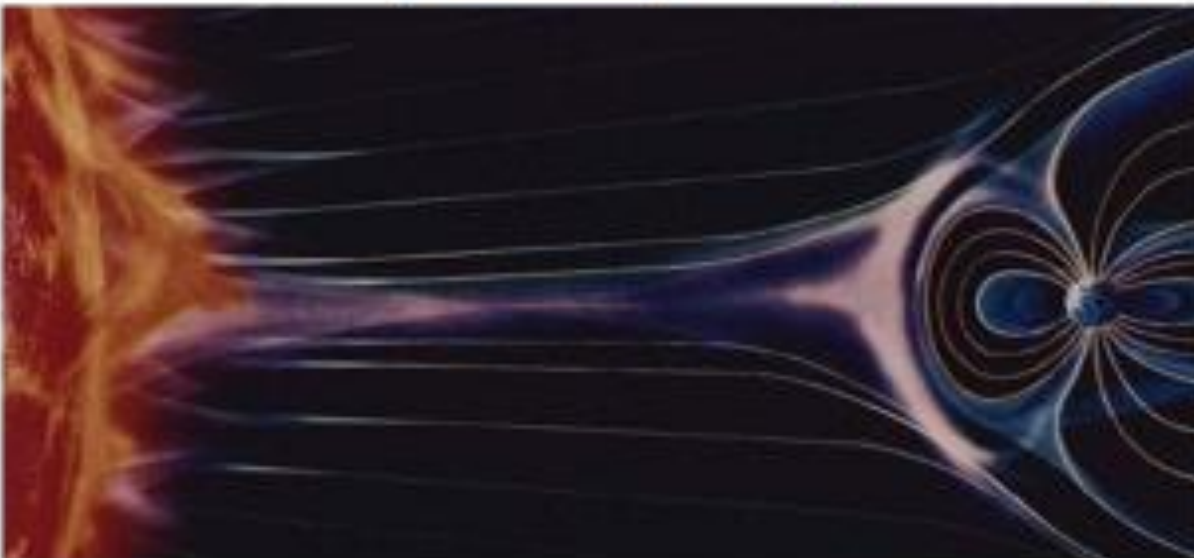
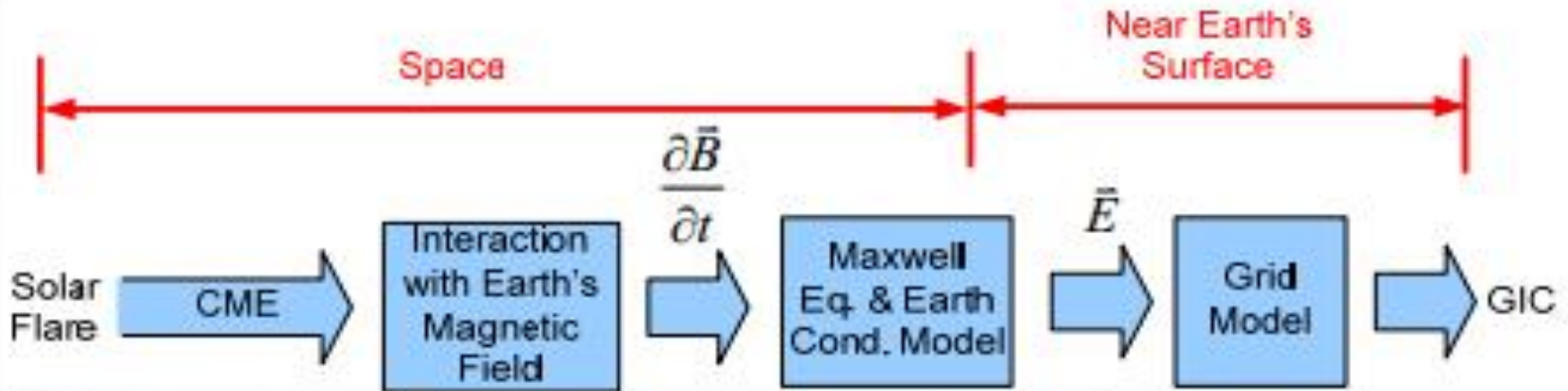
NERC GMD Reliability Standards

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Space Weather Workshop 2015, Boulder, CO
April 16, 2015

RELIABILITY | ACCOUNTABILITY



Potential Impacts on the Power System



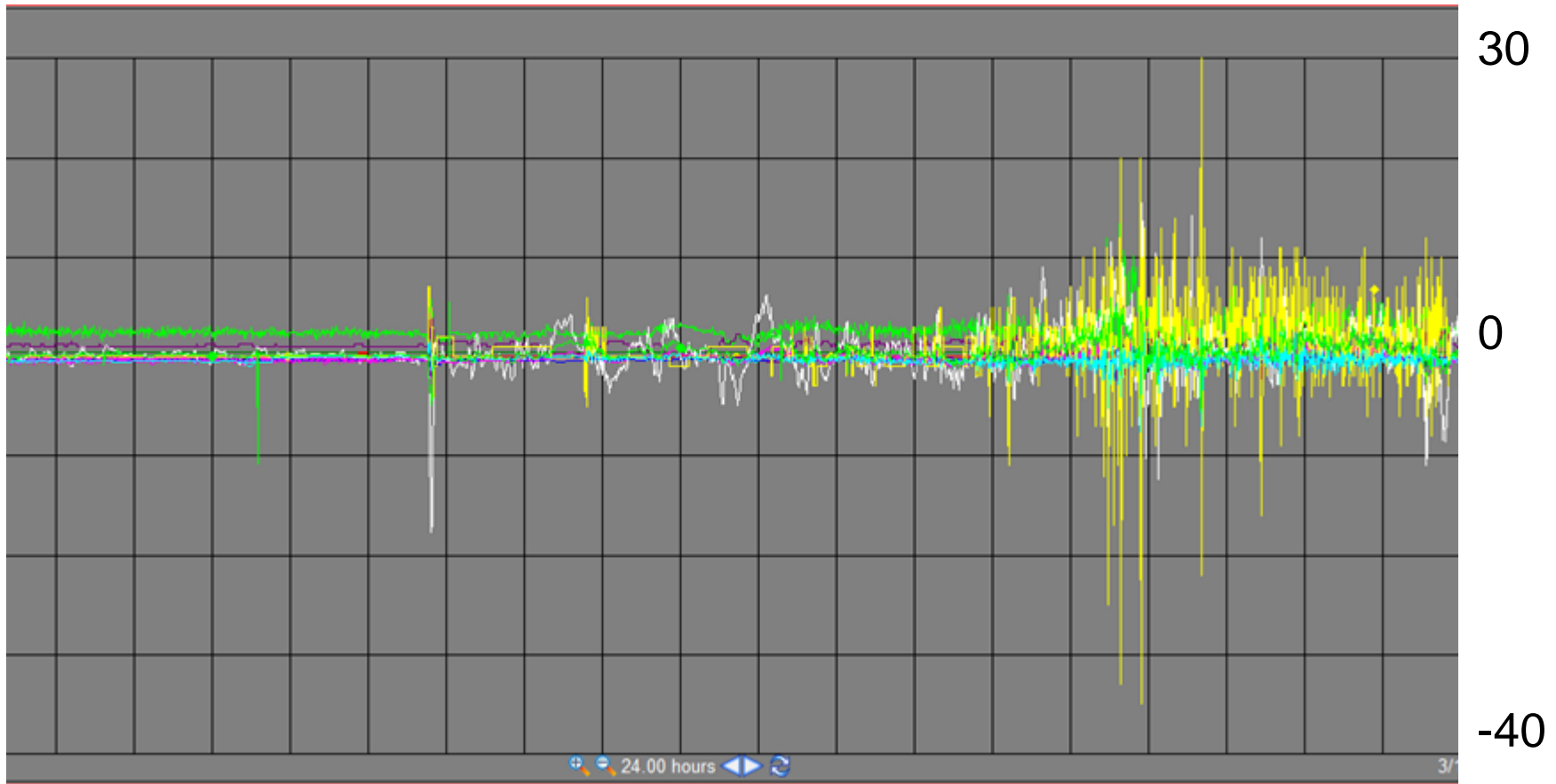
Geomagnetically-induced currents (GIC) can cause:

- Increased reactive power consumption
- Transformer heating
- Protection System misoperation

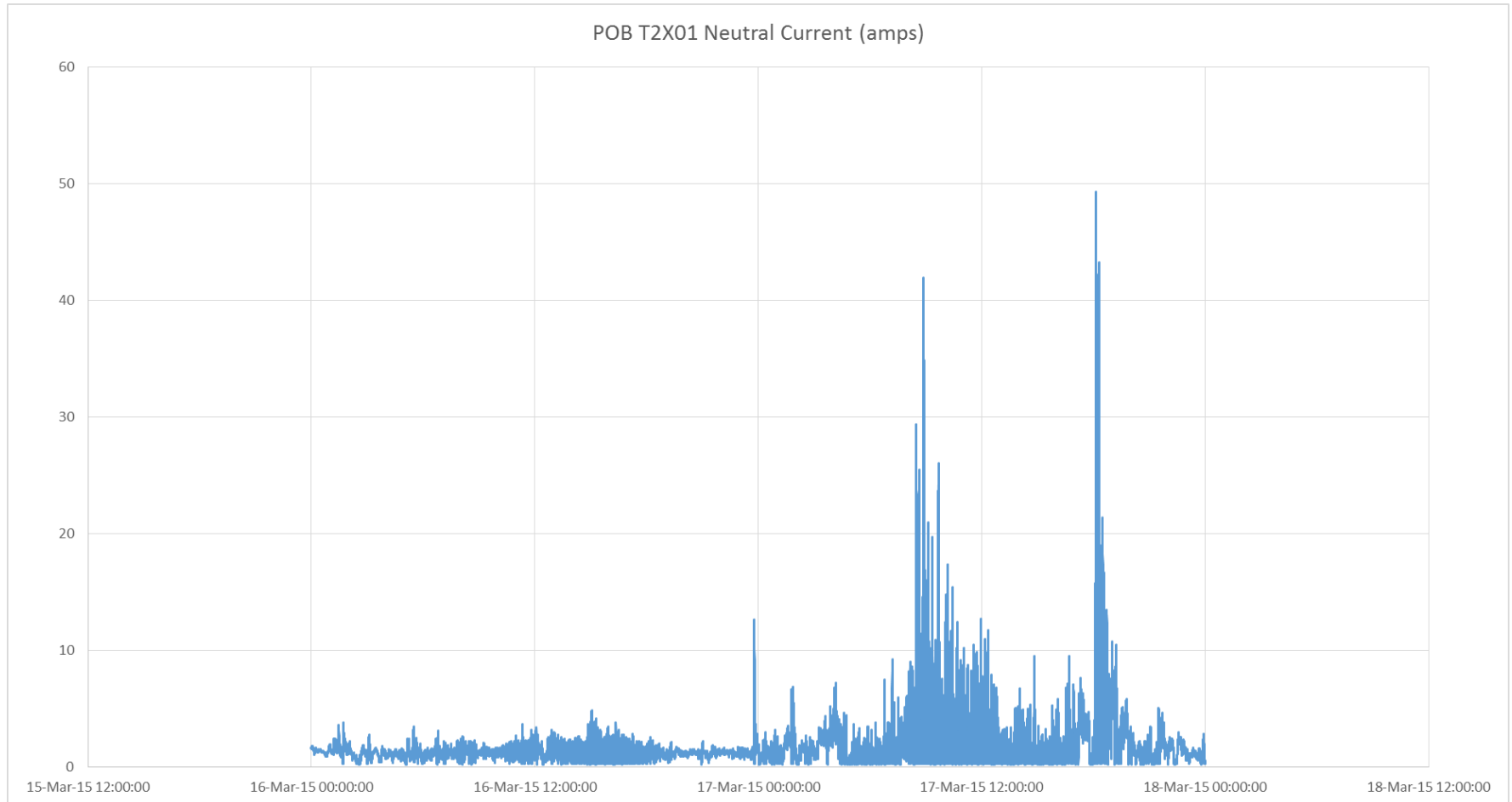
- Requires Reliability Coordinators (RC) to develop Operating Plans to coordinate GMD Operating Procedures in their area
- Requires Transmission Operators (TOP) to develop GMD Operating Procedures that include:
 - Steps to receive space weather information
 - System Operator actions based on predetermined conditions
- Applies to RCs and TOPs with grounded wye transformers >200 kV on the high side
- U.S. enforcement date April 1, 2015

- Ahead of the storm (1-3 days)
 - Raise situational awareness
 - Posture the system—e.g. return or stop outages
- Day of storm (hours ahead or imminent)
 - Monitor GIC detectors/magnetometers/reactive reserves
 - Add generation and reactive resources
- Real Time
 - Redispatch generation, based on pre-study
 - Selectively, remove lines and transformers from service, based on pre-study
 - Boost voltage schedules on generation, where necessary

AE	Missouri Ave DC	-1	10	BC	Waugh Chapel 500-3 GIC	0	4
AEPT	Dumont TR2 GMD	3	90	BC	Waugh Chapel 500-4 GIC	1	4
AEPT	Jacksons . 1 GMD	-1	90	BC	Conastone 500-2 GIC	0	4
AEPT	Jefferson XF2 GMD 2nd Harmo	0	90	BC	Conastone 500-4 GIC	0	4
AEPT	Jefferson XF2 GMD 5th Harmo	0	90	COMED	7 State Line TR81 GIC	2	75
AEPT	Kammer .400 GMD	-1	90	COMED	154 Libertyville TR83 GIC	2	75
AEPT	Marysville . 1 GMD	5	90	COMED	80 Pontiac TR82 GIC	0	75
AEPT	Rockport TR3 GMD	-1	90	DOM	Carson TX2 GIC	-1	270
AEPT	Scanton . 3 GMD	0	90	DOM	Dooms TX9 GIC	2	210
AEPT	Sullivan TR GMD	-2	90	DOM	Pleasant View TX3 GIC	6	270
APS	Bedington Tran 1 SMD	1	20	DOM	Suffolk TX7 GIC	0	270
APS	Bedington Tran 2 SMD	1	20	PE	Centerpoint 1TR DC	-2	10
APS	Bedington Tran 3 SMD	0	20	PE	Limerick 4ATR DC	-2	10
APS	Bedington Tran 4 SMD	1	20	PE	Limerick 4BTR DC	0	10
APS	Black Oak Tran 3 SMD	0	20	PE	Peach Bottom 1TR DC	2	10
APS	Cabot Tran 3 SMD	4	20	PE	Whitpain 1TR DC	0	10
APS	Doubs Tran 1 SMD	0	20	PE	Whitpain 2TR DC	0	10
APS	Doubs Tran 2 SMD	0	20	PE	Whitpain 3TR DC	-3	10
APS	Doubs Tran 3 SMD	0	20	PEP	Chalkpoint 500-6 GIC	4	10
APS	Doubs Tran 4 SMD	0	20	External			
APS	Hatfield Tran 1 SMD	0	20				
APS	Pruntytown Tran 4 SMD	0	20	NYPP	Fishkill BK1 GIC	8	10
APS	Meadowbrook SMD Total	4	80	NYPP	Hurley BK1 GIC	-2	10
APS	Meadowbrook Tran 1 SMD	1	20				
APS	Meadowbrook Tran 2 SMD	1	20				
APS	Meadowbrook Tran 3 SMD	1	20				
APS	Meadowbrook Tran 4 SMD	1	20				
APS	Wylie Ridge Tran 5 SMD	0	20				
APS	Wylie Ridge Tran 7 SMD	0	20				
APS	Yukon Tran 3 SMD	0	20				



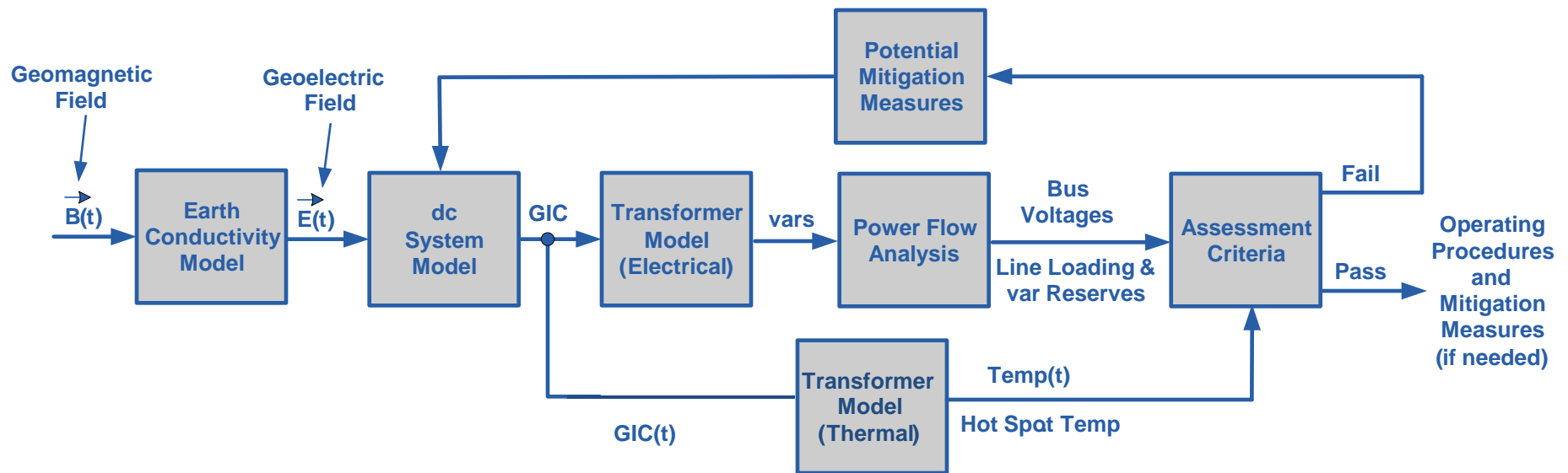
Transformer Neutral Amps



Two Rivers, Wisconsin (~44 degrees⁰ N)

- Requires a **GMD Vulnerability Assessment** of the system for its ability to withstand a Benchmark GMD Event without causing a wide area blackout, voltage collapse, or damage to transformers, once every 5 years.
 - Applicability: Planning Coordinators (PCs), Transmission Planners (TPs)
- Requires a **Transformer thermal impact assessment** to ensure that all high-side, wye grounded transformers connected at 200kV or higher will not overheat based on the Benchmark GMD Event
 - Applicability: Generator Owners (GOs), Transmission Owners (TOs)

GMD Assessment Process Overview



- Calculate GICs and increases in reactive power consumption

$$E_{\text{peak}} = E_{\text{benchmark}} \times \alpha \times \beta \text{ (in V/km)}$$

E_{peak} = Benchmark geoelectric field magnitude at System location

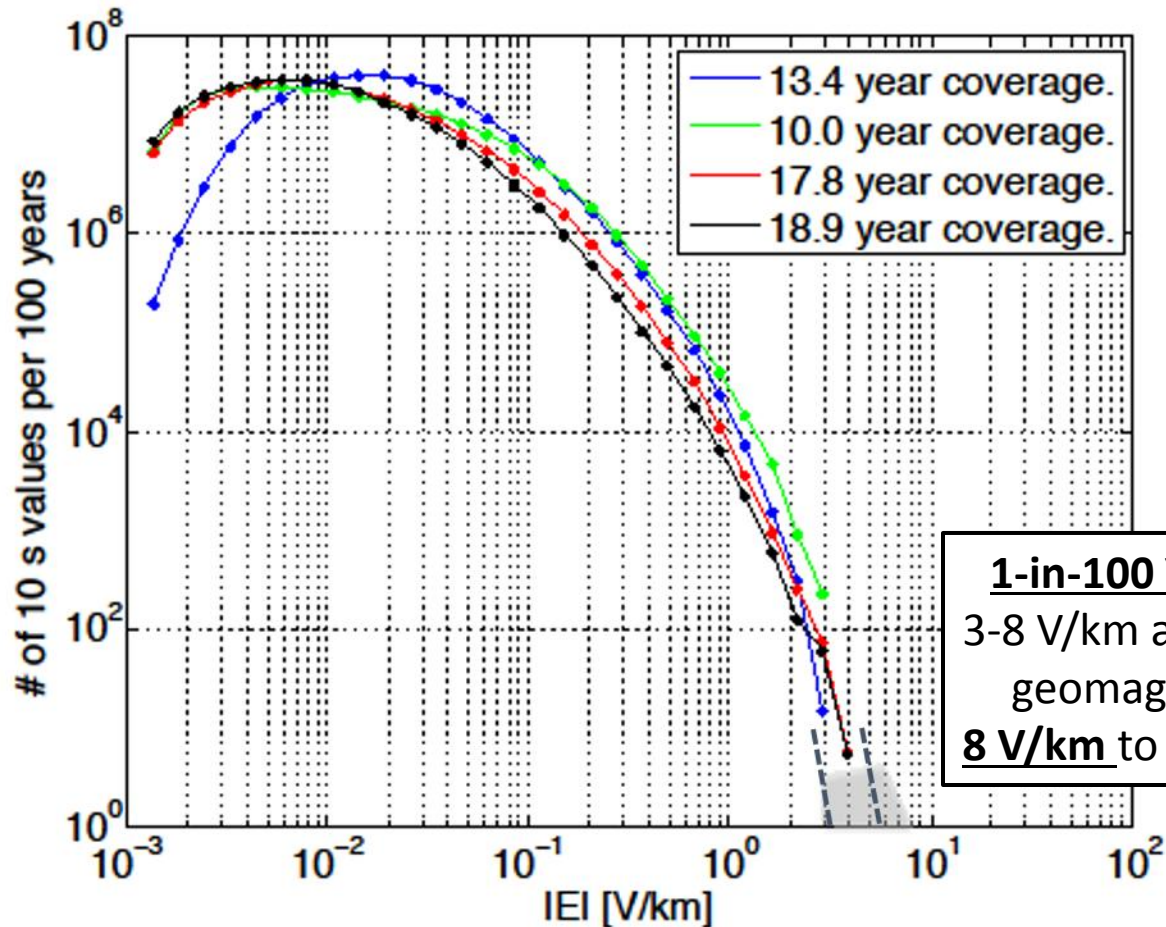
$E_{\text{benchmark}}$ = 8 V/km

α = Factor adjustment for geomagnetic latitude

β = Factor adjustment for regional Earth conductivity model

Major power flow analysis programs (PSS/E, PSLF, and PowerWorld) have GIC calculation modules

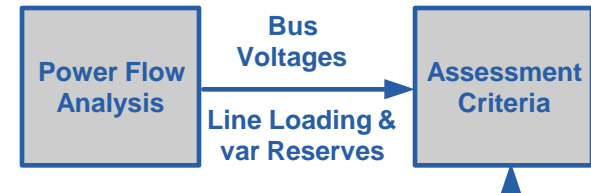
Reference Geoelectric Field Amplitude



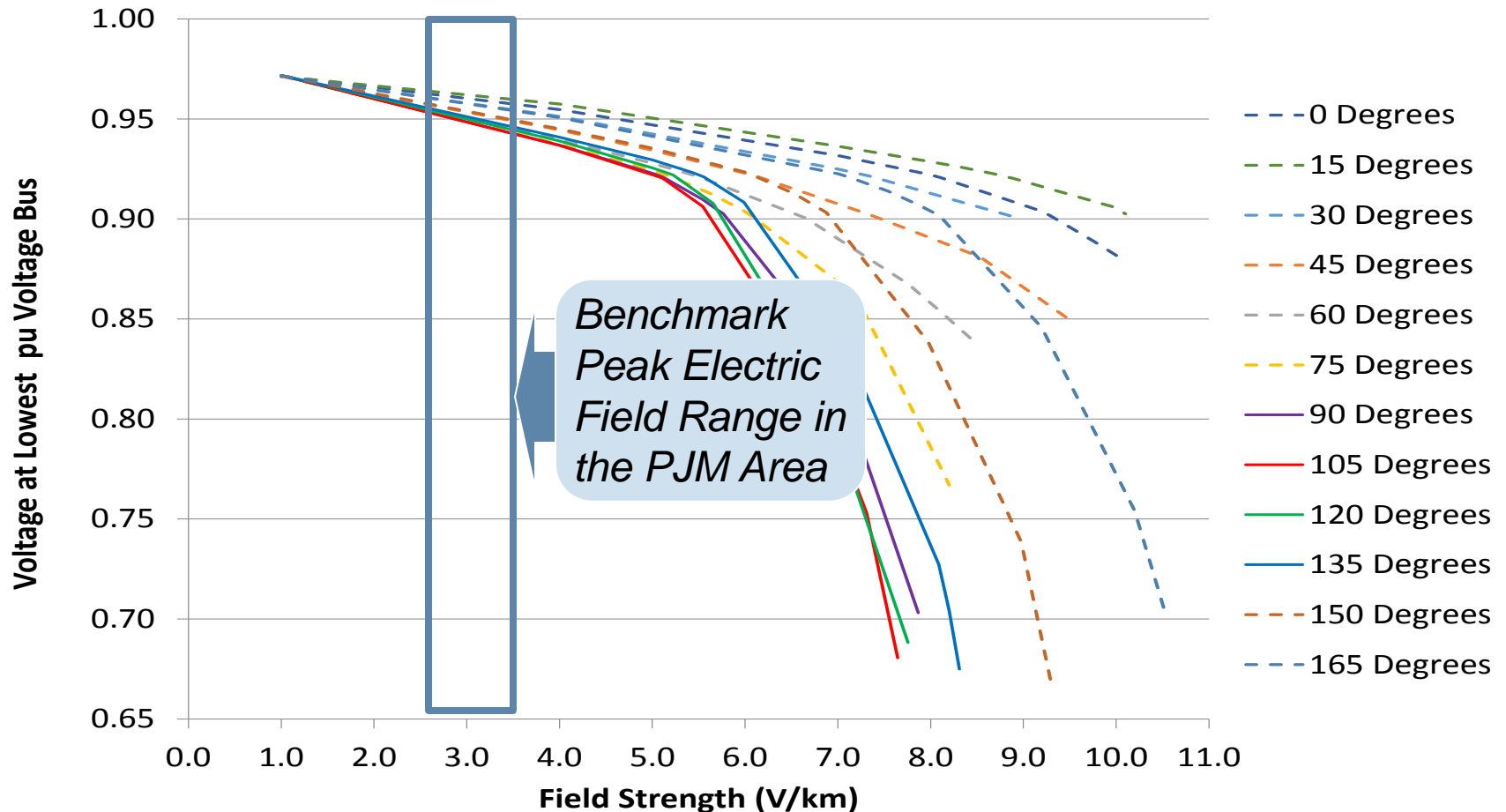
1-in-100 Year Occurrence
3-8 V/km at 60° N
geomagnetic latitude
8 V/km to be conservative

Statistical occurrence of spatially averaged high-latitude geoelectric field amplitudes from IMAGE magnetometer data (1993 – 2013)

- Add reactive power losses due to GIC into the AC power flow
 - Consider impact of harmonic currents
 - Solve AC power flow case
 - Did the system collapse or go into cascading? Not a trivial problem – planners are used to looking for individual equipment limit violations
 - If the system is able to withstand the Benchmark GMD event, then the assessment is complete.
 - If the system cannot withstand the Benchmark GMD event, go to R7

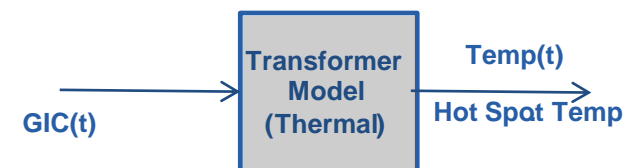


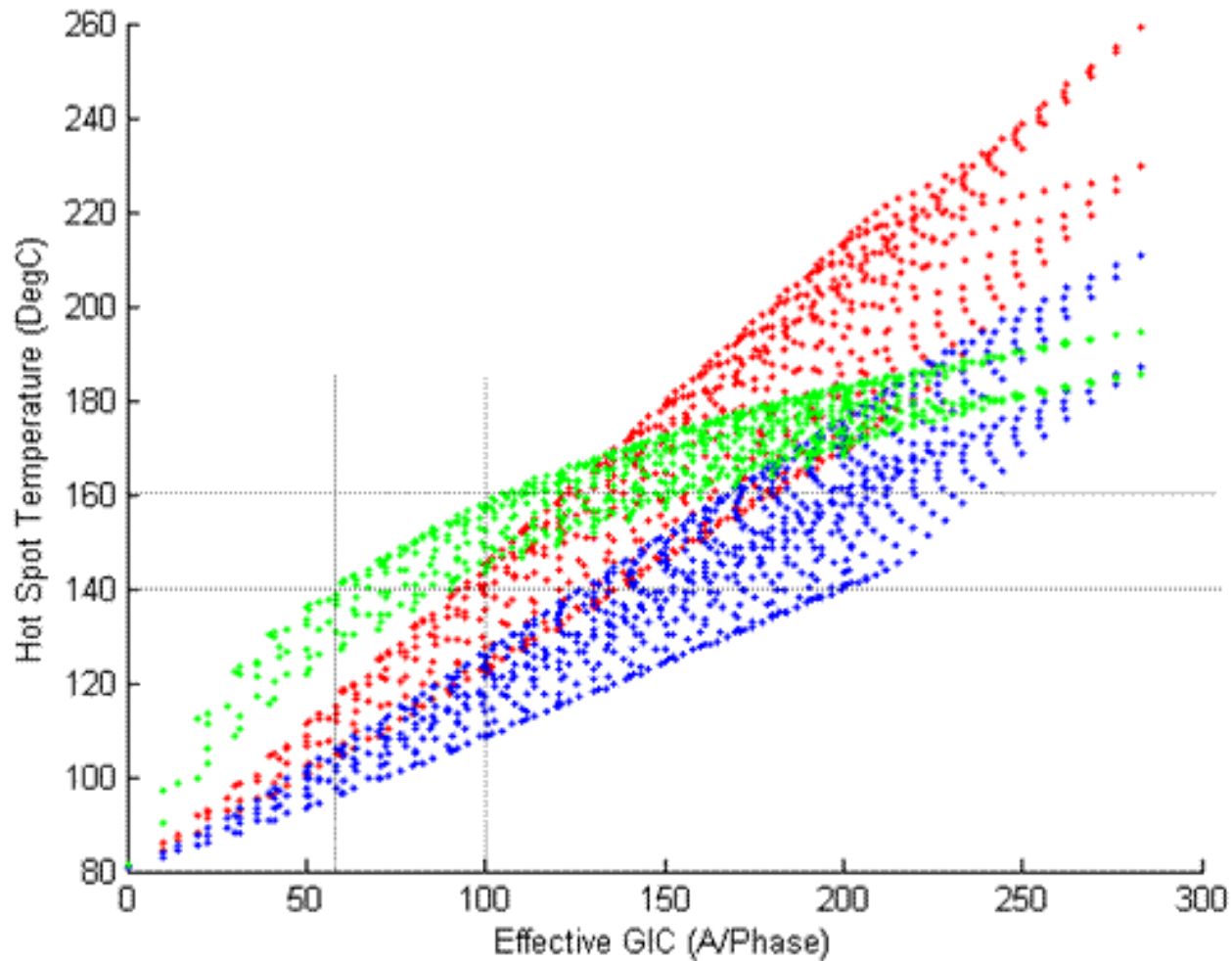
Voltage Performance, Spring Light Load



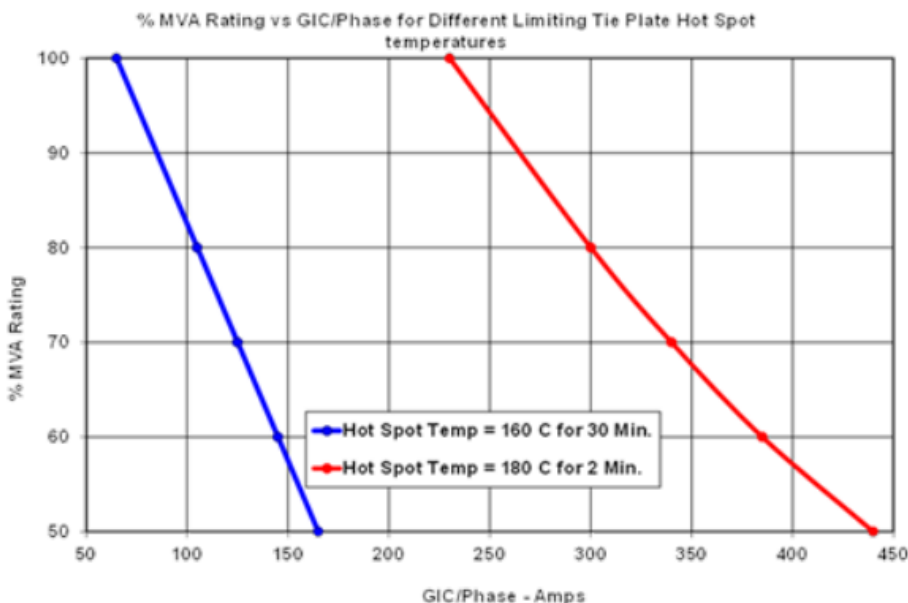
Asset owners:

- Obtain GIC peak value and time series
- If the calculated GIC for the transformer is less than 75 amps, then no further assessment is required
- If the calculated GIC for the transformer is more than 75 amps, a more detailed analysis should be done

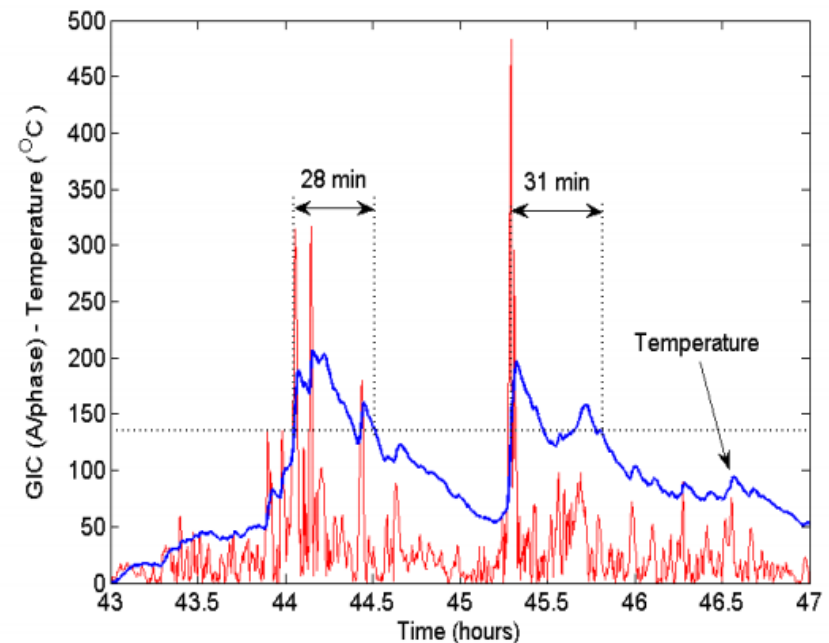




- Consult manufacturer or IEEE Std C57.91 for temperature limits
- Assessment approaches: Rectangular Snip



Transformer manufacturer
capability curves



Thermal response simulation

- Transformers with the highest GICs (divide by 3 phases; peak electric field in PJM is ~3V/km)

Transformer Description	Area	Avg Neutral Current, pu (3 phase)	Avg Neutral Amps (3 phase)
765/26 #2	AEP	1.147	86.557
765/26 #1	AEP	1.059	79.952
500/22 #1	PJM	0.645	74.491
765/345 #1	AEP	0.919	69.322
765/138 #2	AEP	0.883	66.610
765/500 #1	AEP	0.870	65.680
500/22 #1	DVP	0.565	65.260
345/25 #5	CE	0.388	64.975
500/25 #1	PJM	0.554	63.982
500/22 #1	PJM	0.554	63.982
500/230 #1	DVP	0.539	62.256
500/22 #1	PJM	0.539	62.219
345/138/34.5 # 1	CE	0.369	61.810
765/345/33 #1	CE	0.726	54.762
345/22 #8	DEO&K	0.320	53.517
500/230 #2	DVP	0.443	51.158
500/230 #1	DVP	0.442	51.062
765/345 #3	AEP	0.651	49.102
345/34.5 #1	AEP	0.283	47.431

A number of entities expressed concerns with the proposed implementation plan so it was revised as follows:

